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ORIGINAL ARTICLE

Sustainable wastewater management from shale oil production wells: emerging opportunities and barriers

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Abstract

During the production from shale oil formations, the produced water has been dedicated to different procedures such as chemical enhanced oil recoveries, drilling mud making (e.g., for various purposes of lubrication and cooling) and hydraulic fracturing. One of the main challenges of wastewater treatment corresponds to (TDS) total dissolved solids. To measure the required water needed for different processes, it is necessary to proceed with every step saving and then make an average to calculate the required freshwater. In this regard, we have selected five different oil wells with the same rock and reservoir characteristics. SOW#3 has the highest rate of treatment (26%) and SOW#1 has the minimum treated wastewater during hydraulic fracturing processes. It corresponds to the large volume of solid and oil particles, which remained in the treatment devices. However, it is observed that SOW#1 has the highest rate of treatment (32%) and SOW#4 has the minimum treated wastewater (14%) in chemical enhanced oil recovery methods. On the other hand, SOW#3 has the highest rate of treatment (27%) and SOW#5 has the minimum treated wastewater from drilling mud preparation and other well facilities. It is observed that SOW#1 has the highest rate of treatment (27%) and SOW#5 has the minimum saving water during hydraulic fracturing processes, SOW#1 has the highest rate of treatment (38%) and SOW#4 has the minimum saving water (9%).

Keywords Shale oil formations · Total dissolved solids · Treated wastewater · Fresh water

Introduction

Conventional reservoirs can generate economic flow rates and produce economical amounts of oil and gas without stimulus operations or any special recycling process. A conventional high-to-medium permeability reservoir is defined so that it can be drilled in that vertical well or networked at deep distances from the reservoir of that well, and finally that well has an economic production rate and the rate of oil and gas recovery from it(Fakhru'l-Razi et al. 2009; Jiménez et al. 2018). While an unconventional reservoir is a reservoir that does not have an economical flow rate, the economic volume of oil and gas is not produced without unique recovery methods or ancillary operations such as steam injection

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technology. Notable unconventional reservoirs include dense gaseous sands, methane coal, heavy oil and gaseous shales. Rising prices and advancing technology are critical to their future development. Unconventional sources are probably substantial, but their scattering properties are not well-known. It is clear that they exist in large quantities but does not flow easily to the well in terms of economic recovery.

Emerging technologies and advancements in unconventional reservoirs would represent a new policy toward energy systems. It is noted that providing sustainable demand of various industries. Today, with declining production from conventional oil and gas reservoirs and increasing demand for fossil fuels, economical oil production from unconventional shales is significant challenges for the petroleum industry(Kelsey et al. 2016; Zou et al. 2019). High volume, long-term potential, reasonable price and unusual attraction in global markets have made unconventional gas the forerunner of future energies. The oil in the underground reservoirs with low permeability has excellent potential for future production. Low permeability, abnormal pressure, gas saturation reservoir, and lack of lower water zone are the four criteria that have unusual oil accumulations in a basin center. Compressible oil sands are an essential oil reservoir in the center of the basin, but not all oil reservoirs are in the center of the sand basin type(ZOU et al. 2013). Advances in drilling technology and well completion will allow geological reservoirs to be well identified and fully explored. Multi-branch wells and well residue management are two critical components in new technologies in developing dense gas reservoirs. Due to the need to better understand and predict the characteristics of the reservoir in reservoirs with low permeability and the use of relevant information in the evaluation of resources to sciences such as geology, reservoir engineering, interpretation of well-surveying diagrams and other related disciplines is needed to achieve this critical matter. In this way, no worries remain in the extraction of oil and natural gas, and there will be a considerable amount of unconventional oil and gas that can be replaced by conventional oil, which will decline in the next 5–20 years.

Here, we aimed to concentrate on the regional case study in one Iranian shale oil formation. Furthermore, due to the state-wide evaluation, unconventional wells can produce lower wastewater values than conventional wells. In this regard, the sheer magnitude of unconventional oil wells in Iranian oilfields to increase the production rate is a vitally essential platform for petroleum industries(Arthur and Cole 2014; Tolmachev et al. 2020). On the other hand, managing these large water quantities due to the dissolving of non-reused materials such as heavy metals and salts would provide significant challenges in treatment processes. Another barrier of previous studies corresponded to the spillage risks of storage or transport leakages during the treatment processes, which can cause severe challenges for petroleum industries. In this study, the treatment procedures would be essential as they can remove waste materials to reduce the hazardous effects on the environment.

Consequently, we aimed to proceed with the optimum wastewater treatment procedures in shale oil formations to virtually eliminate the unnecessary expenses of freshwater supply and transfer to the operational sites. It can be denoted that implementing this treatment facility near the production wells would be more convenient for operators, too, as they can handle the oil production in less time-consuming processes. In addition, life cycle assessment of drilling operations would be more feasible and sustainable, which can further guide operational and environmental issues.

Methodology

During the production from shale oil formations, the produced water has been dedicated to different procedures such as chemical enhanced oil recoveries, drilling mud making (e.g., for various purposes of lubrication and cooling), and hydraulic fracturing. One of the main challenges of wastewater treatment corresponds to (TDS) total dissolved solids. Well, completion is another type of operational process, which needs large water volumes to proceed(Freedman et al. 2017; Kondash et al. 2017). Water flowback has contained formation brines, fracturing fluids, and small colloids of oil in the primary stages. To measure the required water needed for different processes, it is necessary to proceed with every step saving and then make an average to calculate the required freshwater. In this regard, we have selected five different oil wells with the same rock and reservoir characteristics.

Today, the release of certain specific organic pollutants into the environment with a long half-life, by remaining in nature, enters the food chain and eventually transmits to humans. These substances in the body cause various complications, including mutations in various genes and carcinogenesis. In recent years, new advanced oxidation (AOP) methods have been developed based on the production of hydroxyl free radicals and have a remarkable ability to decompose various organic materials(Oturan and Aaron 2014; Rekhate and Srivastava 2020). In this paper, various methods of chemical treatment of hard decomposition materials with emphasis on advanced oxidation of industrial wastewater are discussed, and their strengths and weaknesses are discussed. In general, these methods have the advantages of high speed and efficiency of treatment, but due to high costs and less complexity, they are used as a single process in the treatment of decomposed complex wastewater and are often used in combination with other treatment processes. The Photo Fenton-flotation technique, while having higher oxidation power, is very different from conventional methods in terms of operating conditions and adverse products for the environment. Ultrasonic waves and advanced oxidation technology such as plasma, Fenton, photo-Fenton, wet oxidation by peroxide, ozone and photo-catalysts such as O_3 / UV have been used to remove hard decomposing contaminants from water sources. In general, the factors affecting AOP processes include pH, temperature, concentration, type of contaminant, type of catalyst, and concentration of reactants. Advanced oxidation processes can also degrade contaminants that remain in the effluent after the treatment process. In most cases, AOP is used as a pretreatment for industrial effluents containing toxic and hard decomposing materials before the biological treatment process.

In the Fe^{2+} / H_2O_2 system, some raw materials are sometimes intermediates during the removal process, which remain unchanged during the oxidation reaction. This may be due to the production of intermediates (mostly organic acids) that can form complexes with ferric ions such as $Fe^{3+}(RCO_2)^{2+}$ that are reluctant to react with active intermediates and prevent the degradation process from progressing. With UV light in this process (photo-Fenton process), the rate of degradation of pollutants and their mineralization is significantly increased. In the process of photo-Fenton, in addition to the reactions mentioned in the section related to Fenton, the following reactions take place, which increase the efficiency of the process of degradation of pollutants:

$$Fe(OH)^{2+} + h\upsilon \rightarrow Fe^{2+} + {}^{\bullet}OH$$

$$H_2O_2 + h\upsilon \rightarrow 2{}^{\bullet}OH$$

So far, various methods such as activated sludge, biofilter, Fenton, O_3 / H_2O_2, O_3 / UV electrocoagulation have been used to remove paint from wastewater. In the last decade, the application of chemical coagulation technology to remove various contaminants of turbidity, hardness, arsenic from water has been investigated. Electrocoagulation is highly efficient at removing paint due to electric current and is an excellent alternative to expensive chemical methods. In the process of electrical coagulation, the electrodes are affected by a strong electric field and oxidation and reduction reactions, and by producing coagulants on-site based on the principles of absorption, neutralization of electric charge, and complexation, the desired contaminants are removed from the aqueous environment. By directly injecting hydrogen peroxide into the medium under the electrocoagulation process in which iron ions are present, the Fenton process can be induced in aqueous samples. The Fenton process is obtained by combining two substances, hydrogen peroxide and iron ions. In this process, ionized forms of iron react as a catalyst with the substance hydrogen peroxide and increase the production and rate of radical formation of hydroxyl.

Results

Treated water in treatment processes

Water is one of the essential materials during hydraulic fracturing processes to build the fracturing fluid; it should be provided before commencing the process; therefore, if these water volumes can be provided from the treatment processes to minimize the freshwater supply. It can be deduced the unnecessary expenses of water transfer. Five production wells were considered in this study to measure wastewater treated in the processes. The treated wastewater is calculated in Table 1 for each production well.

The percentage of each treated wastewater in total treated wastewater from hydraulic fracturing is plotted in Fig. 1. SOW denotes shale oil wells, and it is observed that SOW#3 has the highest rate of treatment (26%), and SOW#1 has the minimum treated wastewater. It corresponds to the large volume of solid and oil particles, which remained in the treatment devices.

Water is an essential part of every chemical enhanced oil recovery process; it should be provided before commencing the injection processes; therefore, water volumes can be provided from the treatment processes to minimize the freshwater supply. It can be deduced the unnecessary expenses of water transfer. Four production wells were considered in this study to measure wastewater treated in the processes, as SOW#3 is not a suitable choice for enhanced oil recovery processes. It corresponds to the low productivity rate from this well, and we, therefore, ignore this well from our evaluations. The treated wastewater is calculated in Table 2 for each production well.

The percentage of each treated wastewater in total treated wastewater from chemical enhanced oil recovery methods is plotted in Fig. 2. It is observed that SOW#1 has the highest rate of treatment (32%) and SOW#4 has the minimum treated wastewater (14%). It corresponds to the large volume of solid and oil particles which remained in the treatment devices.

Due to the implications of water in drilling mud preparation and other well facilities, required water should be provided before commencing the process; therefore, these

Table 1 Average treated water in each shale oil well in MMSCF/Day during hydraulic fracturing

Well no	Treated water in average (MMSCF/Day)
SOW#1	2.95
SOW#2	4.15
SOW#3	4.55
SOW#4	2.85
SOW#5	3.25

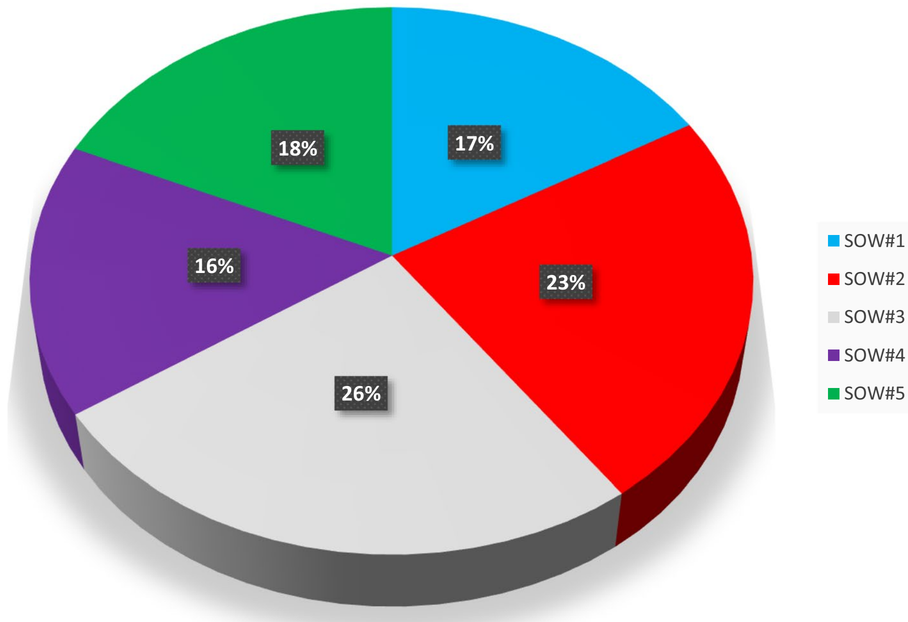

Fig. 1 Treated wastewater for each shale oil well during hydraulic fracturing

Table 2 Average treated water in each shale oil well in MMSCF/Day during chemical enhanced oil recovery

Well no	Treated water in average (MMSCF/Day)
SOW#1	9.75
SOW#2	8.85
SOW#4	4.15
SOW#5	7.65

Table 3 Average treated water in each shale oil well in MMSCF/Day during drilling mud preparation and other suitable facilities

Well no	Treated water in average (MMSCF/Day)
SOW#1	1.15
SOW#2	1.25
SOW#3	1.55
SOW#4	0.95
SOW#5	0.9

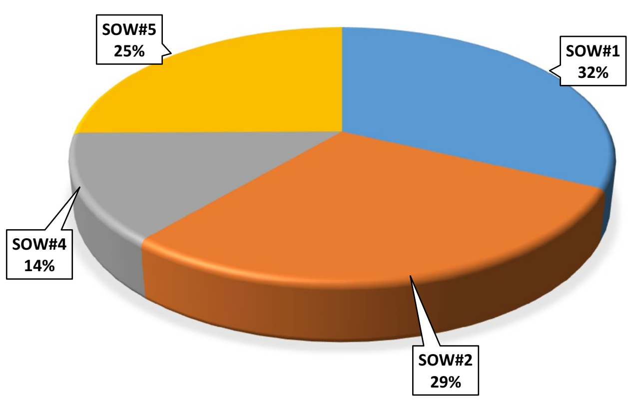

Fig. 2 Treated wastewater for each shale oil well during chemical enhanced oil recovery

water volumes can be provided from the treatment processes to minimize the freshwater supply. It can be deduced the unnecessary expenses of water transfer. Five production wells were considered in this study to measure wastewater

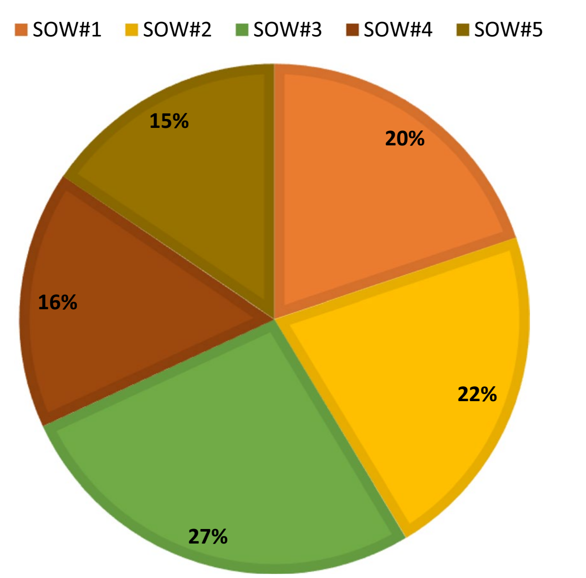

Fig. 3 Treated wastewater for each shale oil well during drilling mud preparation and other well facilities

Table 4 Average saving water in each shale oil well in MMSCF/Day during hydraulic fracturing

Well no	Saving water on average (MMSCF/Day)
SOW#1	1.5
SOW#2	1.15
SOW#3	1.2
SOW#4	1.05
SOW#5	0.75

Table 5 Average saving water in each shale oil well in MMSCF/Day during chemical enhanced oil recovery

Well no	Saving water on average (MMSCF/Day)
SOW#1	5.85
SOW#2	4.25
SOW#4	1.35
SOW#5	3.95

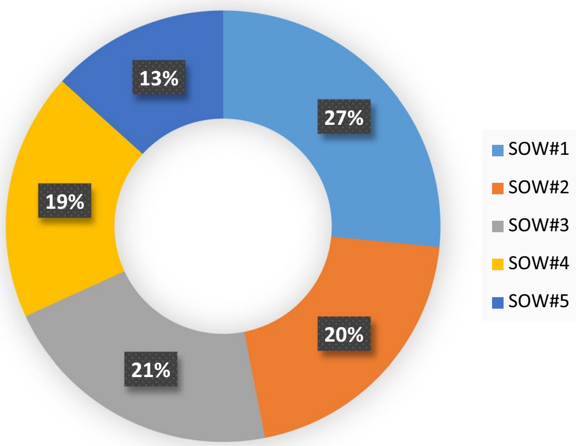

Fig. 4 Saving water for each shale oil well during hydraulic fracturing

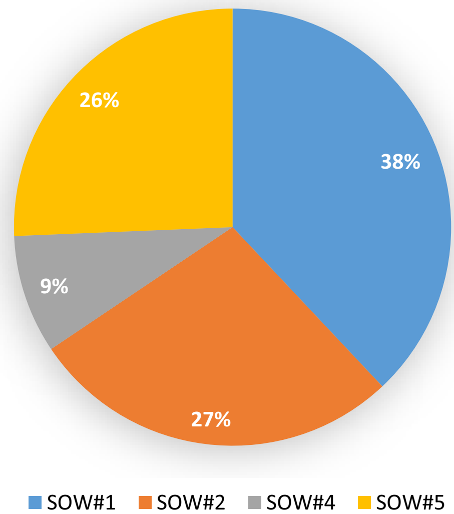

Fig. 5 Saving water for each shale oil well during chemical enhanced oil recovery

treated in the processes. The treated wastewater is calculated in Table 3 for each production well.

The percentage of each treated wastewater in total treated wastewater from drilling mud preparation and other well facilities is plotted in Fig. 3. It is observed that SOW#3 has the highest rate of treatment (27%) and SOW#5 has the minimum treated wastewater. It corresponds to the large volume of solid and oil particles, which remained in the treatment devices.

Saving water in treatment processes

Water is one of the essential materials during hydraulic fracturing processes to build the fracturing fluid; it should be provided before commencing the process; therefore, if these water volumes can be provided from the treatment processes to minimize the freshwater supply. It can be deduced the unnecessary expenses of water transfer. Five production wells were considered in this study to measure saving water in the processes. The saving water is calculated in Table 4 for each production well.

The percentage of each saving water in total saving water from hydraulic fracturing is plotted in Fig. 4. It is observed that SOW#1 has the highest rate of treatment (27%) and SOW#5 has the minimum saving water. It corresponds to the large volume of solid and oil particles, which remained in the treatment devices.

Water is an essential part of every chemical enhanced oil recovery process; it should be provided before commencing the injection processes; therefore, water volumes can be provided from the treatment processes to minimize the freshwater supply. It can be deduced the unnecessary expenses of water transfer. Four production wells were considered in this study to measure saving water in the processes. It corresponds to the low productivity rate from this well, and we, therefore, ignore this well from our evaluations. The treated wastewater is calculated in Table 5 for each production well.

The percentage of each saving water in total saving water from chemically enhanced oil recovery methods is plotted in Fig. 5. It is observed that SOW#1 has the highest rate of treatment (38%) and SOW#4 has the minimum saving water (9%). It corresponds to the large volume of solid and oil particles, which remained in the treatment devices.

Discussion and conclusions

To reduce the enormous demand of drilling and production industries for freshwater, wastewater reuse policy should be followed seriously by petroleum industries. Moreover, due to the lack of water resources and high expenses of water transfer to oilfield locations, it is suggested to have on-site treatment facilities to develop the oilfield productions more conveniently. To eliminate the hazardous environmental issues, wastewater removal and its disposal would be planned before any treatment processes. Regarding the high salinity of oilwells in this field, heavy solids and metals such as strontium radium and barium would remain in the disposal wells. Thereby, these concerns should be taken into consideration by severe monitoring to increase the well lifetime. Another reason for the indirect injection of wastewater after treatment processes is to reduce the impairment risks of surface and subsurface pollutions, especially in oilfields close to urban and basin areas. During the production from shale oil formations, the produced water has been dedicated to different procedures such as chemical enhanced oil recoveries, drilling mud making (e.g., for various purposes of lubrication and cooling), and hydraulic fracturing. To measure the required water needed for different processes, it is necessary to proceed with every step saving and then make an average to calculate the required freshwater. In this regard, we have selected five different oil wells with the same rock and reservoir characteristics. The main findings of this study are as follows;

- SOW#3 has the highest rate of treatment (26%) and SOW#1 has the minimum treated wastewater during hydraulic fracturing processes. It corresponds to the large volume of solid and oil particles, which remained in the treatment devices.
- It is observed that SOW#1 has the highest rate of treatment (32%) and SOW#4 has the minimum treated wastewater (14%) in chemical enhanced oil recovery methods.
- SOW#3 has the highest rate of treatment (27%) and SOW#5 has the minimum treated wastewater from drilling mud preparation and other well facilities.
- It is observed that SOW#1 has the highest rate of treatment (27%) and SOW#5 has the minimum saving water during hydraulic fracturing processes.
- SOW#1 has the highest rate of treatment (38%) and SOW#4 has the minimum saving water (9%).

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Data Availability All data, models and code generated or used during the study appear in the submitted article.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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